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SUBJECT: Some Comments on the Corona
Susceptibility of Apollo Lunar
Orbital Experiments - Case 320

DATE: December 11, 1970

FROM: W. J. Benden

ABSTRACT

Some significant results obtained by the Apollo Lunar Orbital Experiments (LOE) Corona Susceptibility Review Team are summarized. This memorandum serves as a supplement to the team report which was submitted to MSC management.

The Scientific Instrument Module (SIM) environmental pressure may enhance the possibility of corona in the LOE since it appears to be in the 10^{-3} to 10^{-4} Torr. region. LOE contractors are Acceptance Testing in the 10^{-5} to 10^{-6} Torr. region and although no formal corona analysis has been performed, they have based their equipment design on this pressure region. JPL testing of the Gamma Ray Experiment has shown that significant pressure gradients exist internal to the experiment even when the external pressure is in the 10^{-5} to 10^{-7} Torr. A computer program recently developed at GSFC shows promise for use in estimating internal pressure profiles for the LOE. The need to vent LOE covers used to prevent contamination is discussed.

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CORONA SUSCEPTIBILITY OF APOLLO LUNAR
ORBITAL EXPERIMENTS (Bellcomm, Inc.) 22 P

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MEMORANDUM FOR FILE

I. INTRODUCTION

A review team was established at the Manned Spacecraft Center (MSC) for the purpose of identifying potential corona problems in the various Lunar Orbital Experiments (LOE) planned for future Apollo missions. Since the author had been closely involved in past corona problems associated with Apollo equipment, MSC requested his participation as a team member on the review team. Table 1 lists the team members and Table 2 lists the experiments and their suppliers.

The first meeting was held at MSC during the week of September 7, 1970. Each Experiment Manager described the basic operation of his experiment, the type of thermal vacuum testing being performed and problem areas (if any). To date, only the Gamma Ray experiment of the Lunar Orbital Experiments has experienced a corona failure. The failure occurred during Qualification Testing and the fix implemented appears to be satisfactory. Available top level drawings, electrical schematics, potting procedures, and end item specifications were reviewed by the team members. It should be noted that although the team was primarily interested in high voltage areas, it was also interested in low voltage areas where, for example, an arc from a high voltage component may propagate through the grounding system and destroy a sensitive semiconductor circuit. This type of failure occurred during the thermal vacuum testing at MSC of the Superthermal Ion Detector Experiment (SIDE) and in all probability was the cause of failure of the SIDE Cold Cathode Ion Gauge carried to the lunar surface on Apollo 12.

A second team meeting was held at MSC during the week of September 21, 1970. Unfinished items remaining from the first meeting were completed, and a list of questions for each experiment supplier was generated in anticipation of up-coming contractor visits. Table 3 shows a typical set of the general questions.

During the week of September 28, 1970, and the week of October 5, 1970, the team visited all experiment manufacturers. These visits occupied a two-week period with the exception of the last two days spent at the RASPO office in Cambridge, Massachusetts. Here the team reviewed the vendor answers to the question lists, notes and data (drawings, specifications, etc.) accumulated, and laid some of the basic groundwork for the report to be submitted to MSC management. A copy of this team report is available from the author.

This memorandum summarized the highlights of the team effort, the areas of environment and venting (since the author feels these areas should be emphasized), and discusses a computer program approach toward answering some of the unknown parameter questions.* The author sent proposed recommendations (except for item 3-B) to Mr. J. H. Booker on October 29, 1970, for inclusion in the team report. Although not all of the proposed recommendations were accepted by Mr. Booker, they are all interrelated and are included in this memorandum as Appendix A for record.

II. PRESSURE ENVIRONMENT IN THE SIM

At the first MSC team meeting questions were raised concerning the actual ambient pressure in the Scientific Instrument Module (SIM) of the Apollo Service Module before and after SIM door jettison. MSC personnel associated with previous Block 2 Thermal Vacuum Testing (2TV-1) were consulted, and it was generally agreed that the pressure should be about 10^{-3} Torr. and 10^{-4} Torr. before and after door jettison respectively. To date, the team has not received a formal confirmation of these pressures. Calculations¹ taking into account only the nitrogen used for camera operations show pressures greater than 10^{-4} Torr. after door jettison.

In the Lunar Orbit Experiments Performance and Interface Specifications, (SD 69-315) the environmental pressure is given as a hard vacuum of 10^{-6} Torr. Equipment specifications show the experiments are being designed and tested under this hard vacuum condition.

Knowing the pressure dependence of voltage breakdown, one can appreciate the concern generated by this apparent discrepancy on the magnitude of the ambient pressure in the SIM, particularly when one is faced with the task of defining an experiment's corona susceptibility. The above conditions bear

*The computer program approach was not considered in the team report.

a remarkable resemblance to previous pressure and corona problems of the communications equipment installed in the LM aft equipment bay. The equipment was originally designed to operate in a hard vacuum, but in actual use was subjected to ambient pressures in the neighborhood of 10^{-3} Torr. in the LM aft equipment bay.

It is true that some orbital experiments will not be turned on before they leave the SIM area, for example, the Sub-satellite and Mass Spectrometer. Note, however, that it is presently planned to turn the Gamma Ray Spectrometer on while it is still in the SIM bay (before it is extended on its boom). The Laser Altimeter and the X-ray experiment remain in the SIM bay.

The voltage breakdown level at 10^{-6} Torr. is about 20 times the level at atmospheric pressure.² From this basic fact, one can see the importance of venting an electronic package to take advantage of hard vacuum conditions. Of course, an alternate approach toward preventing voltage breakdown is that of pressurizing the electronic package. With the exception of the Laser cavity in the Laser Altimeter, all Lunar Orbital Experiments use the venting approach. The venting approach is an excellent method in principle, but, the use of high vapor pressure materials in and around the high voltage system may prevent the achievement of the desired low pressure environment. Reference 1 indicates those materials found in the LOE that have poor outgassing characteristics.

III. EXPERIMENT VENTING

A recent NASA Goddard report³ describes a method for calculating time varying pressure profiles for various spacecraft compartment configurations and for different outgassing materials contained in these compartments. Program listings, flow diagrams, and typical input-output data are shown in the Appendices of this Goddard report.

Figures 1, 2, and 3, which were taken from Reference 3 show how compartmental pressure is affected by venting and materials. A few major conclusions can be drawn from these curves (note that temperature effects are not included):

1. Comparisons of Figures 1, 2, and 3 show how drastically the curves shift downward with increasing size of the venting orifice.*

*The parameter τ represents the time required for the outgassing rate to reach 0.368 times its initial value.

2. After an initial transient the curves decay very slowly (for some materials). Note: Silicone rubber is used in several places in the Lunar Orbital Experiments.¹
3. The curve slopes indicate that some materials will continue to outgas indefinitely. Thus, the pressure within a compartment can remain well above environmental pressure for extremely long time periods.

Figure 4 shows the experimental set-up used for obtaining the measurement data previously shown on Figures 1, 2, and 3. It should be noted that the silicone rubber was subjected to a 24-hour vacuum soak before performing these tests. Non-outgassed silicone rubber caused erratic pressure gauge readings. All materials were produced in the laboratory in accordance with accepted spacecraft application techniques.³

A recent corona failure (arcing of the 1 Kilovolt terminal) of the Gamma Ray Spectrometer¹ Experiment after approximately six days of thermal vacuum testing further emphasizes that long time periods can be involved before a certain volume, embedded in a piece of equipment, reaches a critical voltage breakdown pressure even when the exterior pressure is that of a hard vacuum.

The failure occurred in a hollow standoff at the base of the three inch photomultiplier tube. It should be noted that the arcing occurred only at the high temperature portion of the thermal cycling. When the temperature was decreased, the corona would extinguish. The chamber vacuum level was maintained at 10^{-5} Torr. or less throughout the six days of testing.

The remaining operating portions of the ALSEP SIDE/CCIG experiment carried to the Lunar Surface by Apollo 12 exhibits arcing symptoms when the temperature reaches the neighborhood of 55° C. Earth transmitted commands are used to turn it off when it reaches this region to prevent permanent damage. This experiment has been on the moon since November 1969 (approximately one year).

During the visit to the Jet Propulsion Laboratory on the Gamma Ray Spectrometer, it was learned that JPL had installed a vacuum gauge internal to the Spectrometer at the mouth of a 1 inch hole and measured 10^{-4} Torr. with an exterior chamber pressure of 10^{-5} Torr. and 10^{-5} Torr. with an exterior pressure of 10^{-7} Torr.

It is the author's opinion that this represents a very significant technique for finding possible pressure gradients within an instrument. Additional JPL testing showed the pressure in this area changed by about 20 to 1 when the temperature was raised from about 70° F. to 120° F. It is felt that the other Lunar Orbital Experiments should be tested in this manner if possible. In addition, measurements should be made as a function of time so that pressure levels can be estimated for the time when the experiment reaches the vicinity of the moon. Ideally, the complete Lunar mission time, temperature, and vacuum profiles should be simulated while internal pressures in the various compartments are being measured.

In looking at a prototype mock-up of the Particle and Fields Subsatellite (at TRW) the author noticed that five 1/2" thick pieces of aluminum honey comb material were used as bulkheads and as might be expected raised a question on the outgassing characteristics of this material. It was pointed out that each cell was vented by a very small pin hole. During a later discussion it was found that the vent holes were used to prevent structural degradation and not intentionally made large enough to prevent corona. It should be noted that this was the case on several experiments. That is, venting calculations were based on relieving internal pressures to a point where mechanical stresses would be negligible, for example, during launch depressurization. These bulkheads offer a source of gas (and moisture) internal to the Subsatellite. From the way the cells are coupled together, it appears that gas could leak from this area for a very long time. The leak rate of these bulkheads should be measured to see if this is really a problem area.

Venting may also be a problem in the S-Band transmitter section of the Subsatellite. TRW pointed out that corona problems had been experienced in the multiplier and bandpass filter areas during their Test and Training Satellite effort but that the bandpass filter had been redesigned. This new design (the overall design is essentially the same as that for the Test and Training Satellite) has been incorporated for the subsatellite. With the exception of the diplexer, the entire transmitter (including the bandpass filter) has no intentional venting.

Venting problems also exist in the "Pent House" area on the Laser Altimeter. As mentioned previously, the details pertaining to corona susceptibility in all of the experiments are contained in the MSC team report, and it is not the purpose of this memorandum to repeat the discussion on these data.

The above paragraphs clearly show that the pressure inside an electronic package, which invariably has many materials (see Reference 1 for LOE materials) outgassing in a thermal-vacuum environment, may be considerably different than the vacuum chamber pressure for extremely long time periods (days, weeks, months, years). Further complications exist in that many of these materials must outgas through a labyrinth of compartments and in some cases must diffuse through potting compounds when the source of gas is trapped air in a potting void. The potential of trapped air exists in all experiments since they all have areas where high voltage potting is done at atmospheric pressure.¹

IV. ADDITIONAL COMMENTS

Since several of the Lunar Orbital Experiments operate on the principle of counting charge pulses, the contractors stated that their instrument had an inherent capability of detecting corona discharges on the high voltage leads. The corona discharge pulses are shown in the telemetry data as abnormal counts. That is, the background level of counts suddenly increases when the corona discharges take place. This inherent capability should be used to its fullest extent by accurately simulating the SIM environment (See Section II) during Acceptance and Qualification testing. There exist possibilities of not detecting corona discharges internal to the power supply (prior to the heavy capacitor filtering) and not detecting corona pulses during dead times in the sample/digital telemetry outputs but it is felt that the probability of detecting corona in the instrument can be greatly increased by simulating the lunar mission pressure, temperature, and time profiles thus using the inherent detection capability of the instrument effectively.

Concern in the areas of high voltage cables, cable terminations, sharp edges on printed circuit boards, sharp solder points, potting and conformal coating procedures, the use of material with poor outgassing characteristics, and poor grounding schemes are expressed in Reference 1. In the author's opinion the LOE have proceeded far enough into the hardware development to make it impractical to make all the design improvements pointed out by the team members. Many of these items are difficult to control during the manufacturing process. Thus, it seems prudent that each experiment be tested and analyzed from a corona viewpoint. Corona testing and analyses are just as important as thermal and vibration testing and analyses. To emphasize this point the reader should refer to Question Seven of Table 3. The answer to this question by all experiment contractors (without exception) was: "No formal corona analysis has been performed on the experiment". It was clear, however, that each manufacturer had taken steps toward preventing corona in his instrument but not all items were considered.

It should also be noted that each contractor became very concerned when asked if he thought his instrument would perform properly (from a corona standpoint) if the SIM environmental pressure was in the region of 10^{-3} to 10^{-4} Torr. This concern is understandable since each experiment had been designed in accordance with hard vacuum conditions.

It is understood that the LOE will not be vacuum tested at KSC because of door jettison, boom extension, and because the chamber can only draw an equivalent of about 200,000 ft. (0.17 Torr.). A look at Paschen's curve² for sparking potential shows this pressure ideal for causing corona conditions. It should also be noted that the various Spectrometers on the LOE are not designed to operate at such a high pressure. It follows that pressure test data from MSC's Block 2 TV-2 tests (See Recommendations in Appendix A) would be very valuable in ascertaining whether the contractor has vacuum tested his experiment sufficiently before delivery to KSC.

V. CONCLUSIONS

1. The SIM ambient pressure, during the planned Apollo missions, appears to be closer to 10^{-3} Torr. rather than a hard vacuum of 10^{-6} Torr. or less.
2. The experiment manufacturers are testing their equipment under hard vacuum conditions and have not designed their equipment to operate at 10^{-3} Torr. No formal corona analyses of the experiments have been made.
3. Even under hard vacuum conditions the pressure inside each experiment can remain in the corona critical pressure region if the experiment is poorly vented and materials with high vapor pressures are utilized in packaging. (Reference 1 has a listing of these materials for each experiment).
4. The nitrogen source which is used in camera operations, provides another means of maintaining relatively high pressure levels in the SIM (in addition to the host of outgassing materials in the experiments) after the door is jettisoned.

5. JPL testing on the Gamma Ray Spectrometer has shown that significant pressure gradients can exist in an experiment when the exterior pressure is in the 10^{-5} to 10^{-7} Torr. region. Their testing has also demonstrated how internal pressures can change by as much as 20 to 1 when the temperature is raised from 70° F. to 120° F.
6. The computer program developed at GSFC offers a possible means for estimating internal pressure as a function of time, outgassing materials, and venting areas in the Lunar Orbital Experiments.
7. A formal corona analysis by each contractor would have prevented many of the potential corona sources noted by the team members.
8. The covers being placed on the experiments to prevent contamination should be adequately vented to help prevent corona.



W. J. Benden

2034-WJB-pjr

Attachment
References
Appendix A
Tables 1-3
Figures 1-4

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REFERENCES

1. Booker, James H., "Report of the Lunar Orbit Experiments Corona Susceptibility Review Team". NASA/MSC, Telemetry and Communications Systems Division, November 1970.
2. Burrowbridge, Donald, and Paul, Fred W., "The Prevention of Electrical Breakdown in Spacecraft". NASA/GSFC, SP-208, Scientific and Technical Information Division, 1969.
3. Scialdone, J. J., "Internal Pressures of a Spacecraft or Other System of Compartments, Connected in Various Ways and Including Outgassing Materials, in a Time-Varying Pressure Environment". NASA/GSFC, N70-24767, August 1969.

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APPENDIX A

The following proposed recommendations to prevent corona problems in the Lunar Orbital Experiments were sent to Mr. J. H. Booker (MSC-EE17) (with the exception of item 3.B):

1. The pressure environment seen by each experiment (including its 3 to 4 day vacuum soak from the earth to the moon) represents a critical parameter when trying to predict corona susceptibility. It is recommended that North American Rockwell reconsider their model of ambient pressure in the SIM bay.
2. MSC should investigate the feasibility of installing vacuum gauges in the SIM bay prior to Block 2 Thermal Vacuum testing (2TV-2) at MSC.* It would be highly desirable to have at least prototype models installed during these tests. That is, to simulate equipment outgassing characteristics as closely as possible. In particular, the nitrogen source, used in camera operations, should be simulated.

Pressure distribution data from the above tests should indicate whether each contractor is testing his instrument to a realistic vacuum profile. In addition, each Principal Investigator (PI) will be provided with data indicating the pressure background to be expected during a mission. Clearly, the instruments on most of these experiments are very sensitive to ion/electron/pressure conditions.

- 3.A. MSC should investigate the feasibility of each contractor installing vacuum gauges internal to his equipment to demonstrate that no significant pressure gradients exist within the package. This should be accomplished at least on a prototype or qualification model as JPL has done in the Gamma Ray experiment.

From these tests it may be found that a critical situation can be relieved by simply drilling a hole in a cover and that this hole spells the difference between success and failure of the entire experiment.

*It is understood that these tests will be performed sometime in January 1971.

Obviously one cannot place a pressure gauge in the r-f circuitry of the subsatellite S-Band Transmitter since drastic detuning would result. However, the author recalls that small cover plates are being used in this area. Maybe a hole can be drilled in a spare cover plate and copper screen placed over it for r-f shielding. The pressure of gas resulting from this hole could then be monitored with a vacuum gauge and thus provide an estimate of internal pressure and, of course, how fast it is changing with time.

In referring to Exhibit B, paragraph 3.3.27b of the End Item Specification* for the Particle and Fields Subsatellite, it is seen that the ability of the equipment to reach the required vacuum in the planned time shall be demonstrated. The above mentioned approach of utilizing vacuum gauges internal to the experiment is the only way known by the author to demonstrate this ability. The Gamma Ray experiment appears to be the only experiment devoting any time toward demonstrating the instrument's degassing ability.

- 3.B. Cost and time schedules may show item 3-A impractical. It follows that MSC should investigate the feasibility of utilizing the Goddard computer program to obtain estimates of internal pressure profiles of the Lunar Orbital Experiments. Exact modeling, of course, would be very difficult; but it is felt that at least some gross estimates could be made from this computer program.
4. There are areas in each experiment where high voltage wire terminations are potted (or conformal coated) at atmospheric pressure. Whenever this approach is taken over vacuum potting, the risk of entrapping air is high.

It is recommended that each contractor provide an exact mechanical mockup of these terminations and that the terminations be potted (or conformal coated) according to the procedure followed on the actual experiment. After curing properly, the terminations should be dissected in a manner which clearly demonstrates that no significant voids exist. This approach should be taken on at least ten samples and photographs should be taken at various dissection levels.

*Contact No. NAS 9-10800 dated May 4, 1970.

Assuming that no significant voids are shown in above tests, additional samples should be prepared and their voltage-pressure breakdown characteristics measured to determine the margin of safety involved.

5. The corona inception level of each type of high voltage cable, used in each experiment, should be measured as a function of pressure to demonstrate its margin of safety. Of course, cable manufacturer data which clearly demonstrates this margin of safety (as a function of pressure) would be sufficient.
6. A formal corona analysis report should be prepared by each contractor. This report should show that the equipment is adequately vented and that no excessive voltage gradients exist anywhere in the experiment. An estimate of the environmental pressure at which the experiment would experience difficulty should also be included in the analysis. The manufacturer should also show in detail how his thermal vacuum testing would catch corona problem areas.
7. It is recommended that MSC seriously consider appointing one of its personnel as the corona expert who would work with the experiment managers until the last flight is delivered. In this way, data obtained during thermal vacuum testing can be carefully scrutinized with possible corona effects being kept in mind. This scrutiny, of course, would be ever present for any anomalies which may occur during future testing. For example, unexplained semiconductor failures may sometimes be traced to intermittent voltage discharge spikes on the ground lines. He may also assist in Item 6 above.
8. If the results of Items 1, 2, and 3 above indicate pressure regions greater than 10^{-5} Torr., the Qualification Model should undergo a complete Lunar Mission Test simulation with corona test equipment monitoring its operation. Complete simulation of pressure, temperature, and time from launch to mission completion should be accomplished.* The slightest indication of corona problems during these special Qualification Tests would dictate the same kind of Mission Profile testing for all flight models to provide confidence that catastrophic failures will not result from small differences in outgassing characteristics.

*With the exception of the subsatellite. Here there appears to be no choice but to demonstrate internal pressures less than 10^{-5} Torr. after its 3-day soak at hard vacuum in lunar orbit.

If it is shown by Items 1, 2, and 3 that the pressure environment is clearly less than 10^{-5} Torr. and if the recommendations indicated under 4, 5, 6, and 7 are followed, it is felt that the experiments can be flown with a high degree of confidence that corona failures will not occur during the mission.

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TABLE 1

LOE CORONA SUSCEPTIBILITY TEAM MEMBERS

NAME	ORGANIZATION
J. H. Booker (Chairman)	MSC - EE17
W. J. Benden	Bellcomm
E. R. Bunker, Jr.	JPL
A. H. Hartsfield	MSC - Boeing
A. J. Pajak	MSC - EE3
H. E. Snyder	MSC - Boeing

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TABLE 2

LUNAR ORBITAL EXPERIMENT CONTRACTORS

NAME	CONTRACTORS
Mass Spectrometer	University of Texas Dallas, Texas
Gamma Ray Spectrometer	JPL* Pasadena, Calif.
Particles and Fields Subsatellite	TRW* Redondo, Calif.
Laser Altimeter	RCA Burlington, Mass.
X-ray Spectrometer	AS&E Cambridge, Mass.

*Analog Technology provides high-voltage power supply

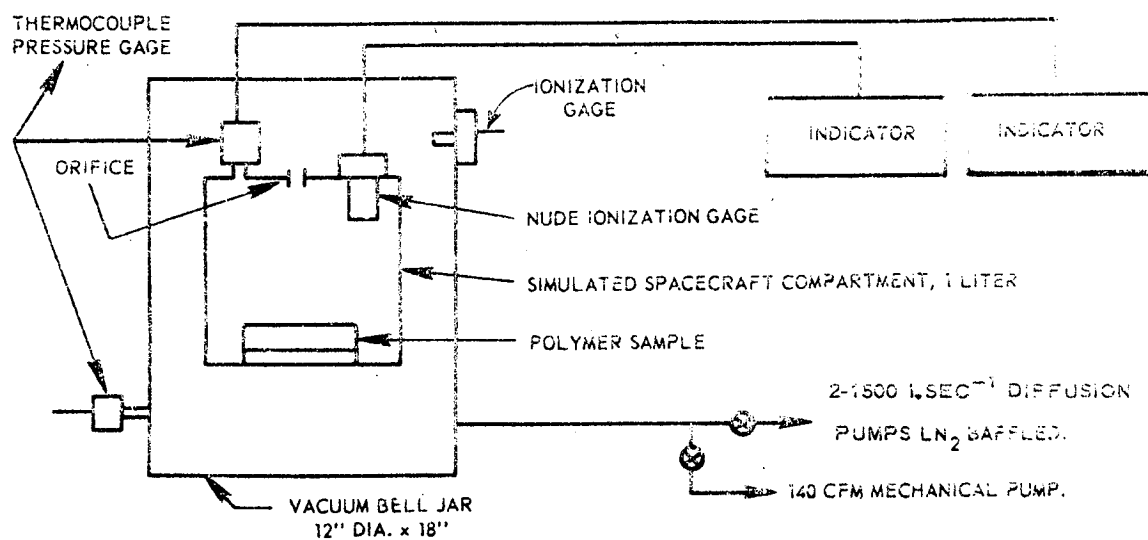
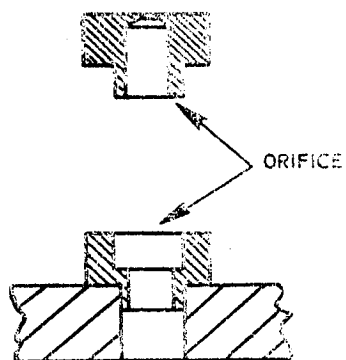


Figure 4-Pressure-Time Test Setup

(Taken from Reference 3)

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TABLE 3

TYPICAL GENERAL QUESTIONS

(Forwarded to each contractor prior to team visit)

1. Is high voltage wire 100% screened by application of overvoltage under vacuum conditions with corona detector?
2. What high voltage testing is done below the system level?
3. What specific procedure is used to pot high voltage components?
4. In high voltage connectors, how is venting assured?
5. How similar are high voltage and RF components to previously flown hardware?
6. How do you plan to prove that the operation of your instrument is not being degraded by corona? What instrumentation or indicators will be used?
7. Was there a corona analysis? If so, give particulars.
8. Has worst case electrical stress analysis been done on all circuits (particularly high "Q" circuits) for both normal and breakdown operation?
9. Are any solid state circuit elements so located that voltage gradients (electric fields) of sufficient magnitude to damage them can be imposed in either normal or faulty operation?
10. What tests are completed or planned specifically for corona?
11. Are all elements of the instrument exercised during thermal vacuum testing?
12. What failures or anomalies have occurred during testing?

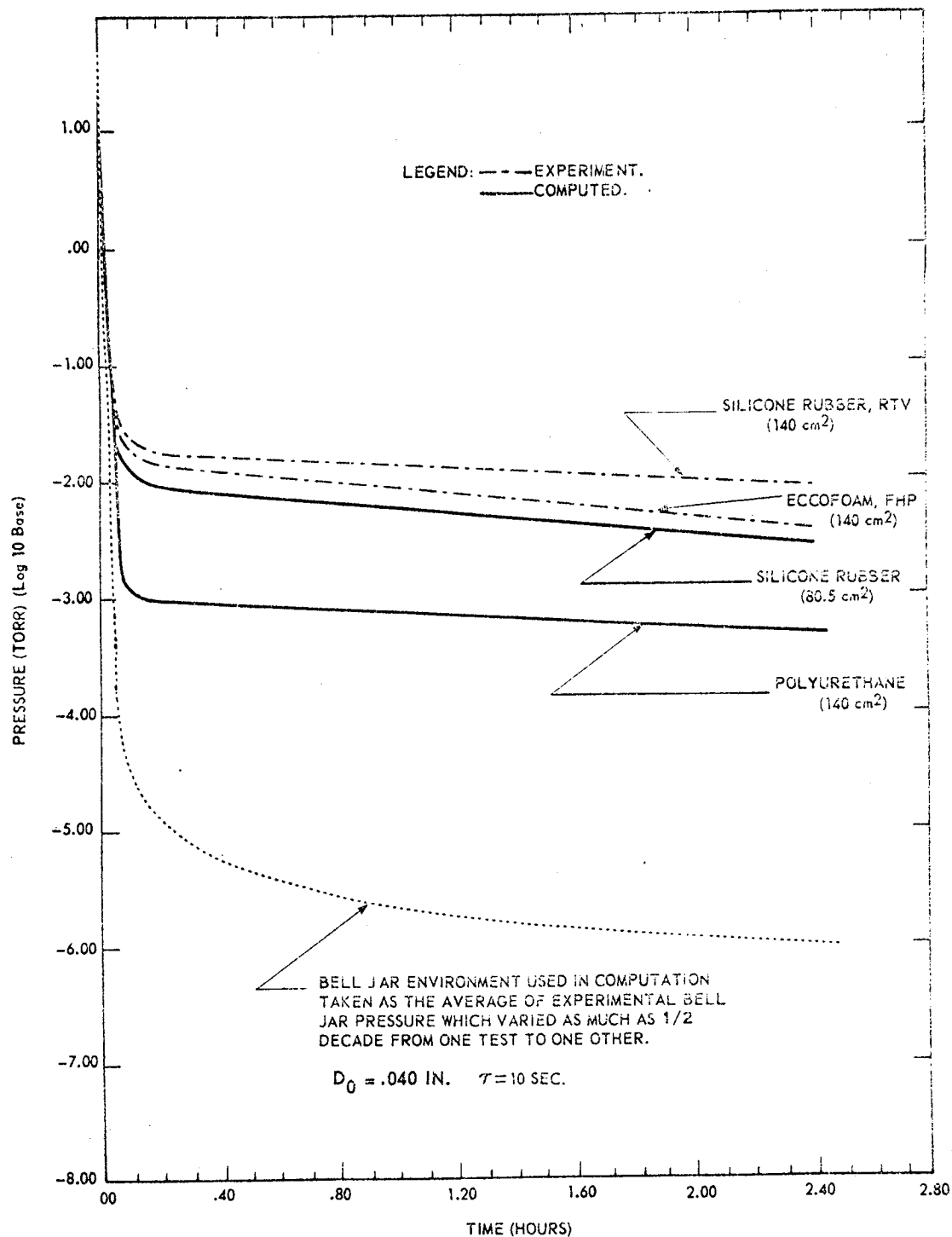


Figure 1 - Comparison of Experimental and Computed Results for a 1-Liter Compartment with Orifice Diameter .040 in., $\tau=10$ sec, Ambient Temperature (Taken from Reference 3).

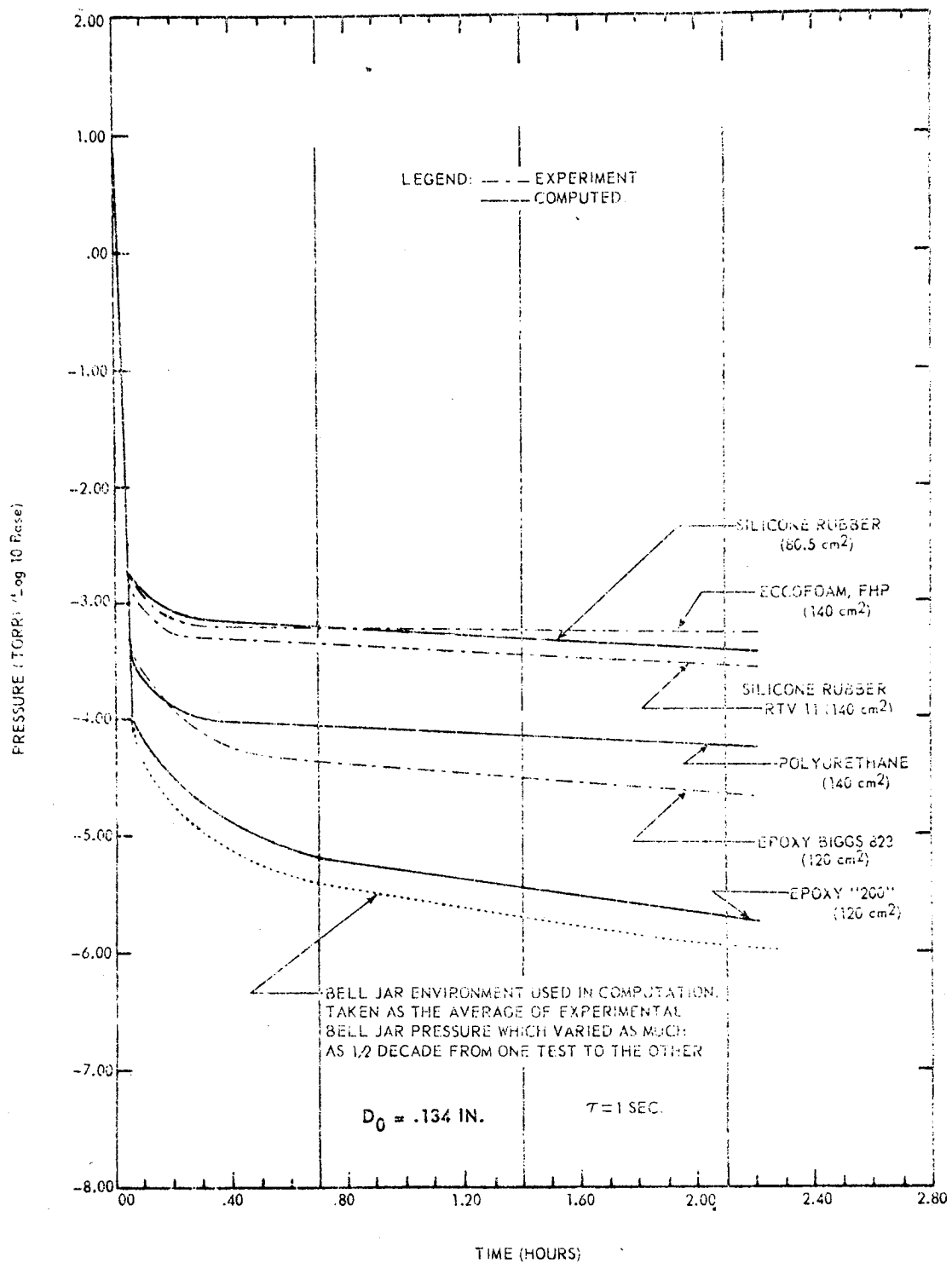


Figure 2 - Comparison of Experimental and Computed Results for a 1-Liter Compartment with Orifice Diameter .134 in., $\tau=1.0$ sec, Ambient Temperature (Taken from Reference 3).

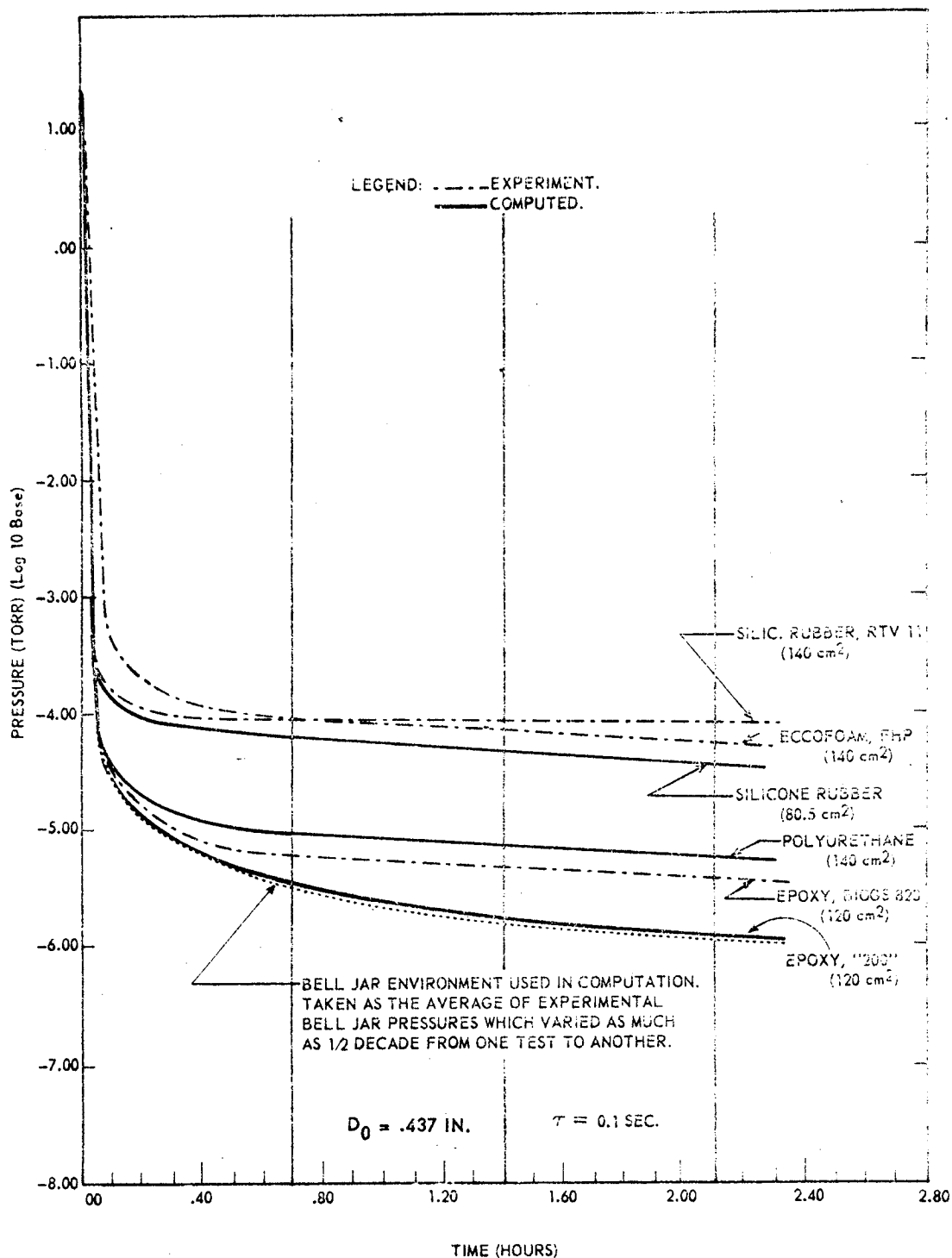


Figure 3 - Comparison of Experimental and Computed Results for a 1-Liter Compartment with Orifice Diameter .437 in, $\tau = .1$ sec, Ambient Temperature (Taken from Reference 3).

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